Evaluating SHOALS Bathymetry using NOAA Hydrographic Survey Data

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ABSTRACT

Approximately 22 square nautical miles of the NOAA hydrographic survey OPR-J343-MI (Approaches to Tampa Bay, FL) were surveyed with the SHOALS system. The SHOALS depths are compared to depth data acquired by the NOAA Ship MT MITCHELL during a complete single-beam echo sounder and 200% side-scan-sonar hydrographic survey of the common area.

INTRODUCTION

The National Oceanic and Atmospheric Administration's (NOAA) National Ocean Service (NOS) Office of Coast Survey maintains and publishes a suite of over 1000 nautical charts covering the coasts of the United States of America and its territories. Approximately 43,000 square nautical miles of this 3.5 million square mile area have been identified as "critical" and in need of a contemporary hydrographic survey. NOS presently operates three hydrographic survey ships and two shore-based field parties. In order to effectively carry out the NOAA charting mission, NOS also contracts hydrographic survey work out to private companies. Additionally, NOS promotes the development and availability of new technologies to increase the efficiency and effectiveness of its survey mission execution. Lidar bathymetry is one such technology that NOS has been involved with since the 1970s.

Airborne lidar bathymetry is attractive for hydrographic surveying because of its utility and its potentially high rates of area coverage. NOS became involved with the U.S. Army Corps of Engineers (USACE) Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) system in 1988. Many of the SHOALS system's depth analysis algorithms were developed by the NOS Office of Coast Survey Nautical Charting Development Laboratory. In an effort to characterize the SHOALS system as a real hydrographic surveying tool, NOS is in the process of conducting lidar surveys in hydrographic project areas that have been recently surveyed by NOAA-proven vertical beam echo sounder and side scan sonar technology. This paper describes one such overlapping survey conducted in the Approaches to Tampa Bay, FL.

Survey Location

Two sites were planned to be surveyed with the SHOALS system: (1) An area located approximately 8 to 12 nautical miles west of the entrance to Tampa Bay, FL, and (2) an area inside Tampa Bay, just east of St. Petersburg, FL (Figures 1 & 2). Only the offshore area was completed. The water clarity of the area selected inside Tampa Bay was not adequate to conduct lidar hydrographic surveying operations. Both of the planned areas are part of the NOAA Ship MT MITCHELL's 1995 survey project, OPR-J343. The primary traffic in the area consists of various commercial ships, tugs and barges, fishing vessels, and recreational boats.

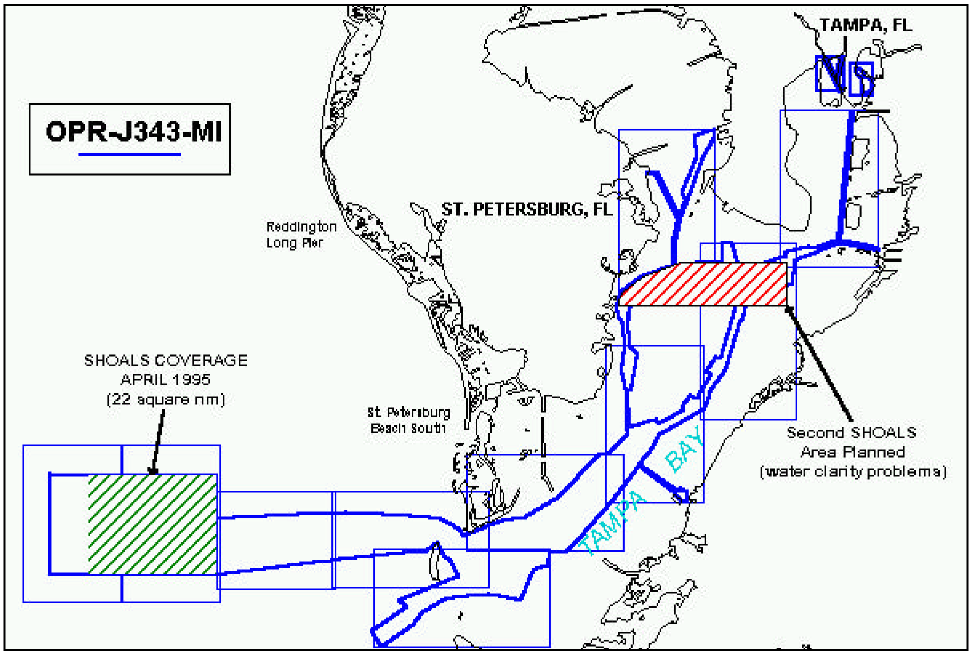

Figure 1 - Area of MT MITCHELL project OPR-J343 surveyed by the SHOALS system

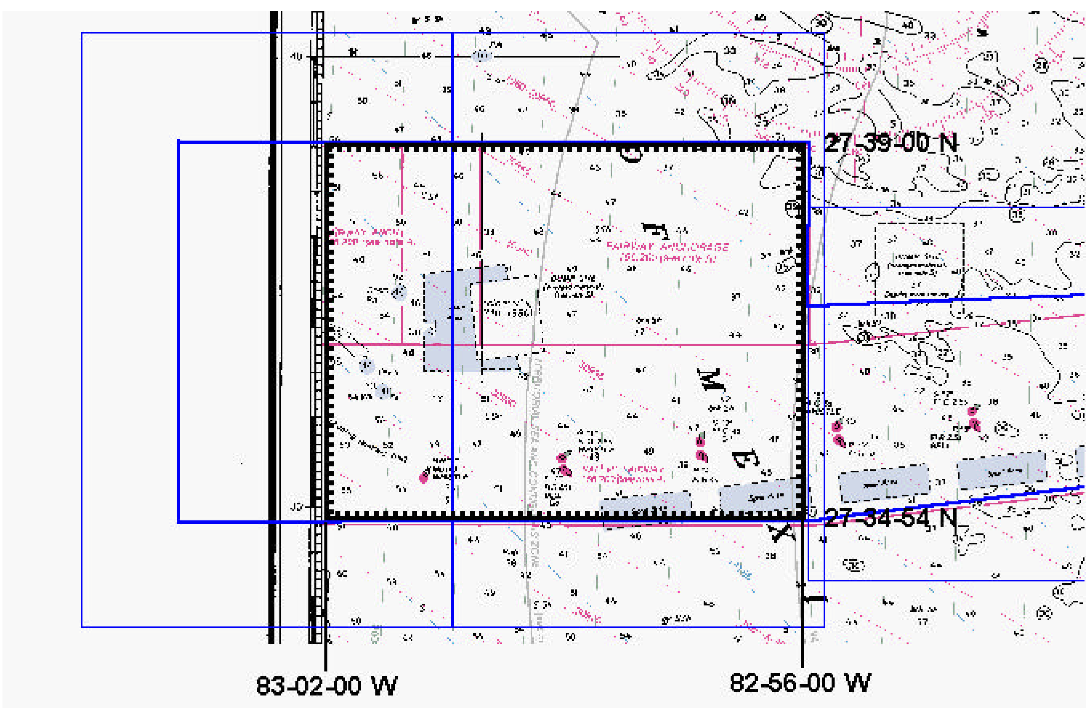

Figure 2 - Portion of NOS Chart 11412 (Approaches to Tampa Bay, FL) showing the common survey area

Survey Techniques

The SHOALS system is designed for use from a helicopter or other aircraft at altitudes ranging from 200 to 1,000 meters. The system is capable of measuring water depths from approximately 1 to 40 meters, depending on water turbidity. Airborne system components include a Nd:YAG (neodymium doped:yttrium,aluminium,garnet) laser transmitter & receiver with a programmable scanner mirror; a differential global positioning system (DGPS) unit; an inertial reference sensor; a system to provide the pilot with real-time navigation guidance; a multi-processor computer system to acquire, initially process, and store all sensed depth data, as well as system time and platform position and attitude; and a status panel to allow the on-board operator to monitor system parameters and confirm that valid data are being collected. A ground-based data processing system produces a quality-checked, tide-corrected depth data set.

A NOAA Aircraft Operations Center Bell 212 helicopter with extra high skid gear served as the platform for the Tampa SHOALS project. A series of parallel flight lines oriented east-west and spaced 80 meters apart were run at an altitude of 200 meters and at a speed of 50 knots. The programmable scanner-mirror reflected the Nd:YAG 200 Hz laser pulses at a constant 20 off-nadir angle, tracing a back-and-forth 100-meter wide swath pattern forward of the helicopter, with an effective sounding grid pattern of 4 meters x 4 meters (Figure 3).

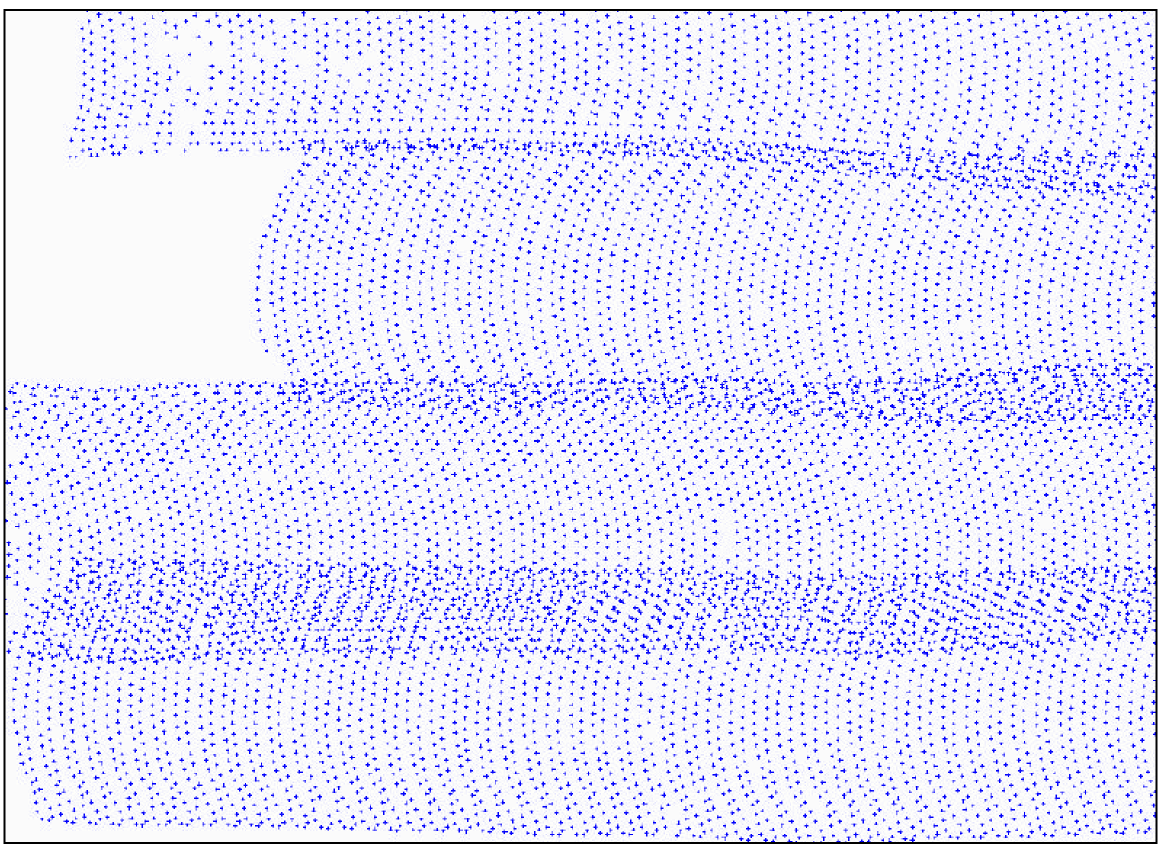

Figure 3 - A series of SHOALS flight line swaths.
Scanned swath soundings are made on a 4m x 4m grid

Over 5.5 million lidar depths were acquired in the 22 nm^2 survey area during April 3, 7-9, and 18, 1995, with 12.2 hours spent in actual surveying (Figure 4).

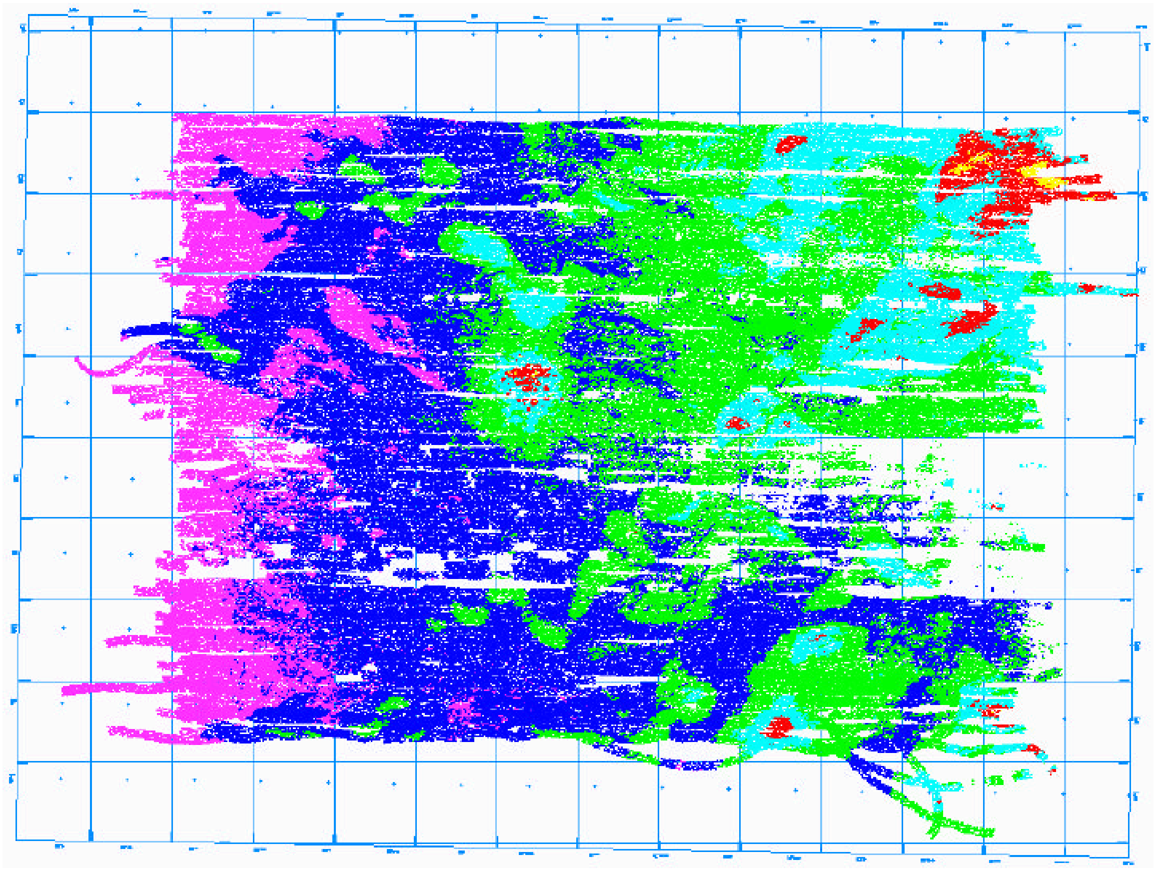

Figure 4 - The series of parallel flight line swaths forming the SHOALS area coverage; void areas are due to rejected data and water clarity problems

NOAA Ship MT MITCHELL surveyed the SHOALS area with vertical-beam acoustic sounding equipment and side scan sonar (SSS). All hydrographic soundings were acquired using Raytheon 6000N Digital Survey Fathometers operating at 100 kHz. Soundings were corrected for speed of sound, vessel static draft, vessel settlement and squat, and sea action. SSS operations were conducted using a slant-range-corrected EG&G Model 260 thermal recorder and a 100 kHz Model 272-T tow fish. Two orthogonal sets of parallel main-scheme survey lines were run at approximately 5 knots to achieve 200% SSS coverage of the bottom (Figure 5). In sufficiently deep water and relatively calm sea conditions the 100-meter SSS range scale was used and adjacent survey lines were run a maximum of 170 meters apart. Elsewhere, the 75-meter SSS range scale was used and successive survey lines were spaced no more than 120 meters apart to obtain adequate coverage. SSS contacts estimated to be 1 meter or greater in height were investigated further by echo sounder development and/or diver least-depth measurement. Echo-sounder development was performed over long and irregular ledges and shoaling areas using as dense as 5 meter line spacing (Figure 5). Over 30,000 soundings were acquired in the 22 nm^2 survey area during May through August, 1995.

Data acquisition was intermittent due to sea conditions offshore and other survey activities conducted elsewhere on the larger OPR-J343 project area. Approximately 24 days were devoted to surveying the common SHOALS area.

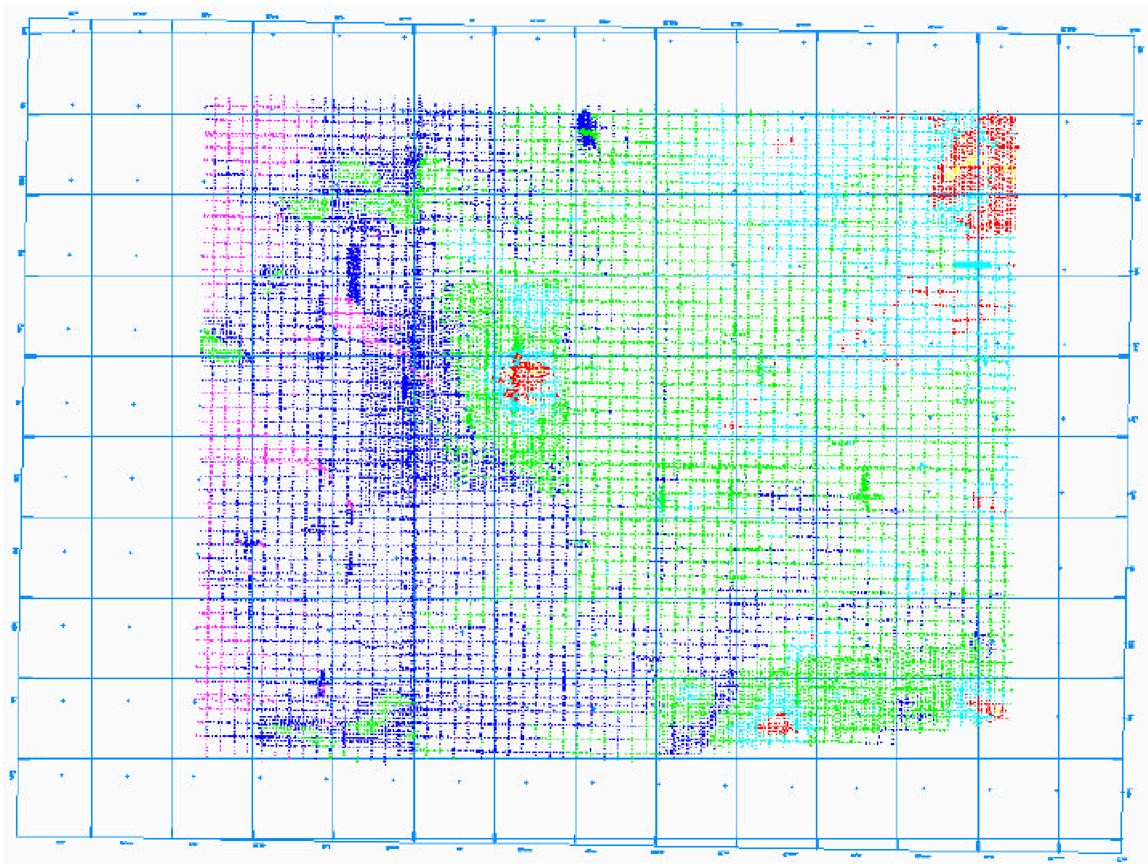

Figure 5 - MT MITCHELL main-scheme and development echo-sounder lines

Both the MT MITCHELL the SHOALS system utilized the differentially-corrected Global Positioning System (DGPS) for horizontal control. The MT MITCHELL survey was conducted in accordance with the NOAA Field Procedures Manual (FPM) requirements for a 1:10,000 scale hydrographic survey: data acquisition operations were conducted under a maximum expected position error of 15 meters (1.5 mm at survey scale). The Tampa SHOALS flight line data was examined carefully during processing and sections of data were rejected whenever erratic positioning was observed. Future NOAA SHOALS projects will be conducted in accordance with appropriate NOAA FPM horizontal control requirements

The tidal datum for this project is Mean Lower Low Water. Predicted tides on the Clearwater Beach, Florida tide gauge were used during the data-acquisition phase of each survey. During each survey project, real tidal water levels were observed at the Reddington Long Pier, FL and St. Petersburg Beach South, FL tide stations to establish a datum for final tide corrections.

DATA ANALYSIS

All depth data from both the SHOALS system and the MT MITCHELL were corrected for observed tides. At the time of this comparison, the MT MITCHELL data had been field edited only; the data had not passed through final NOAA verification processes. Water depths from the two surveys were compared by mapping the MT MITCHELL point data to a Triangulated Irregular Network (TIN) surface created from the SHOALS data. The TIN surface was built using the CARIS HIPS Analysis and Presentation Software from Universal Systems Limited of New Brunswick, Canada. In CARIS, the TIN model is constructed using a Delaunay triangulation algorithm. Each data point in the SHOALS data set formed a vertex in the piece-wise linear triangulated surface. A maximum allowable edge size of 10 meters was specified to prevent the TIN surface from spanning voids or “holidays” in the SHOALS data set.

RESULTS

Figure 6 shows the distribution of the differences computed between the MT MITCHELL acoustic measurements and the corresponding depth values on the 5.5+ million data point SHOALS TIN surface. The mean is approximately -7 centimeters. The computed standard deviation is quite small (0.20 meters). No attempt was made to estimate the individual error components associated with each surveying method. Assuming that the variance of the differences between each survey system’s measurements and the real bottom are equal, the total error associated with each survey is approximately 0.14 meters.

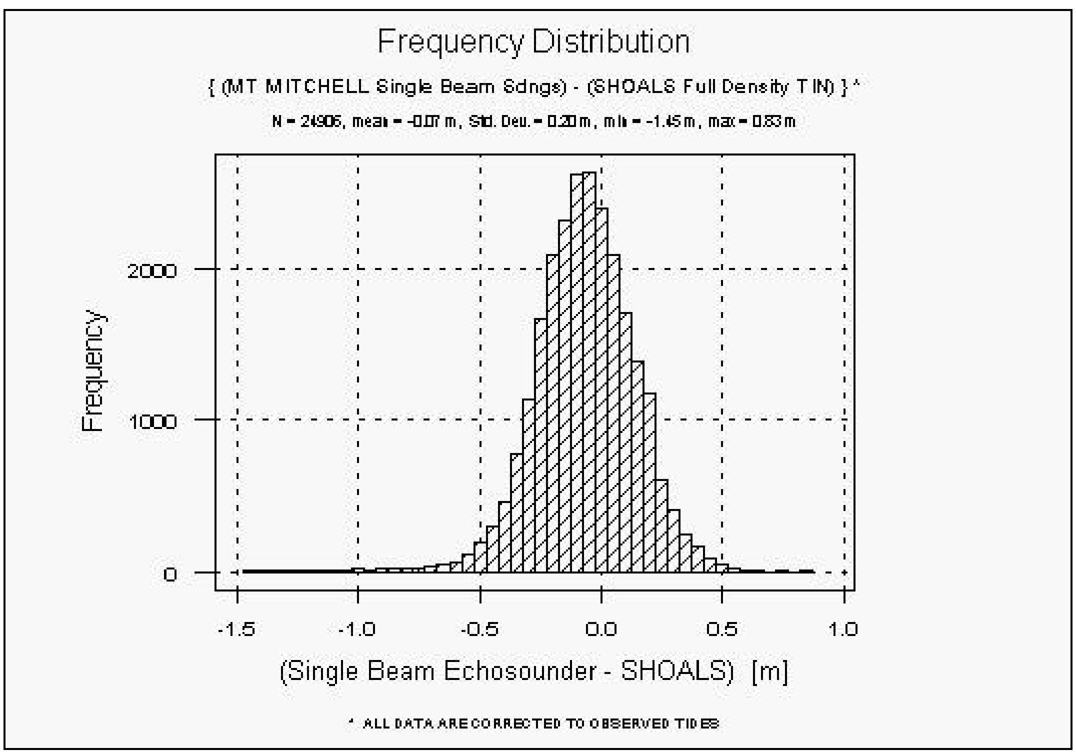

Figure 6 - Depth comparison histogram; each class interval bar represents 0.05 m (5 cm)

Figure 7 shows the relationship of the computed depth differences (acoustic - SHOALS TIN surface) as a function of depth (acoustic). In general, the deviation is insensitive to water depth; note the near unity slope of the linear model least-squares fit between the SHOALS and acoustically measured depths shown in Figure 8. The observed deviation insensitivity with depth is attributed to the minimal lidar propagation biases formed in the extremely clear water conditions encountered during the SHOALS missions.

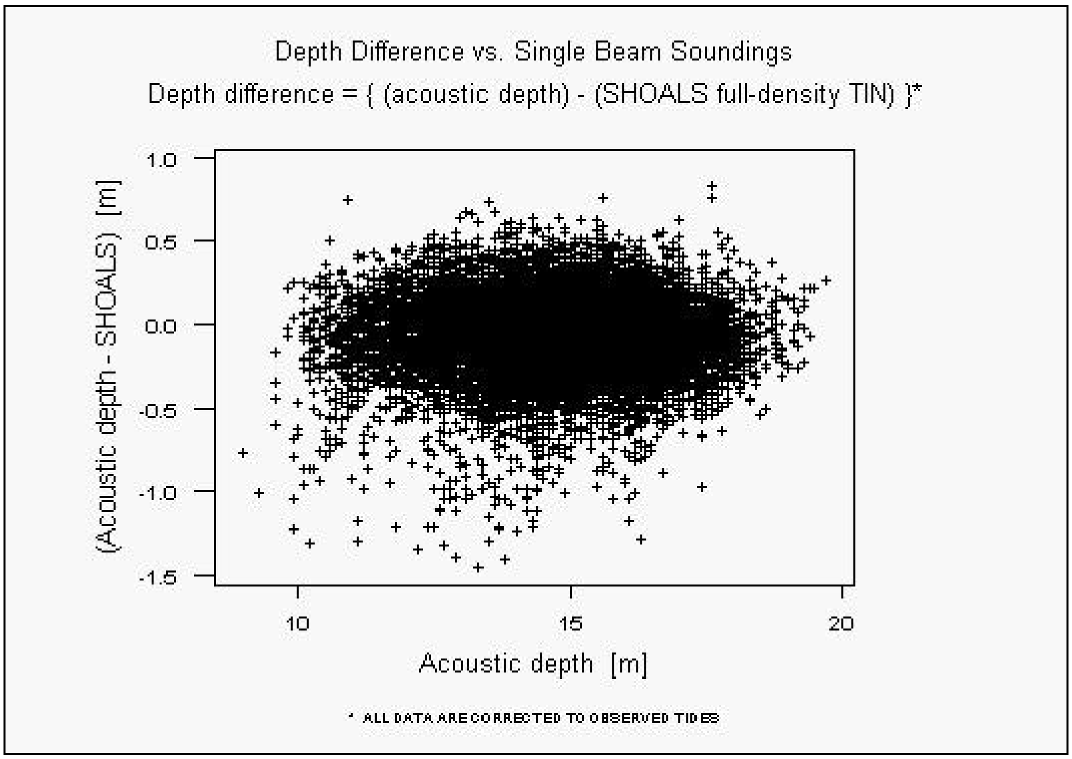

Figure 7 - Depth difference as a function of depth

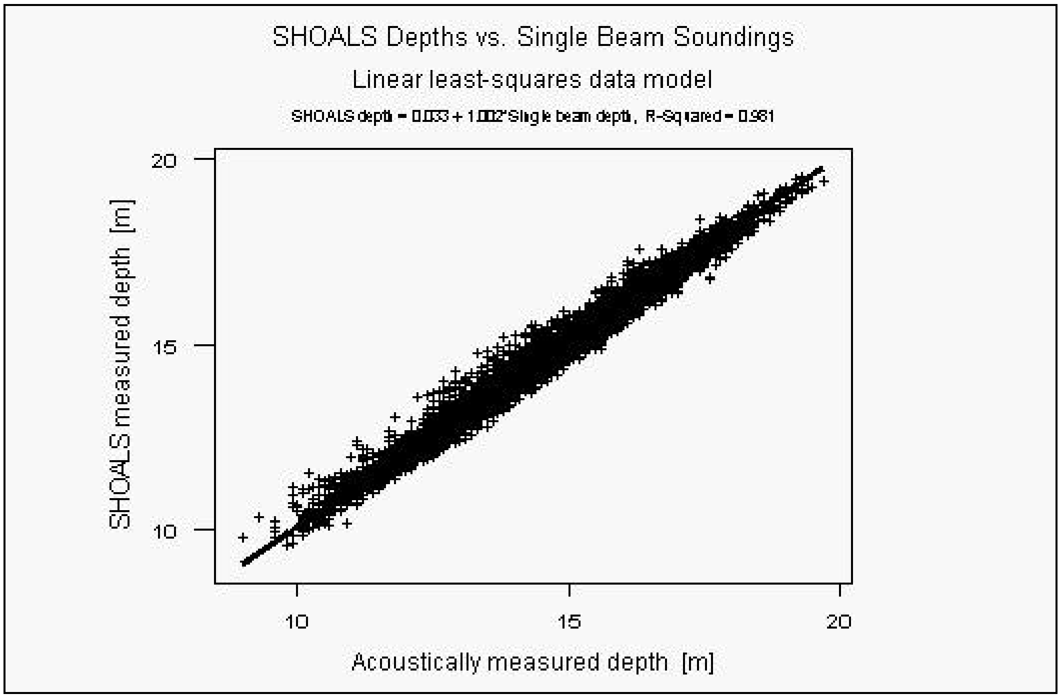

Figure 8 - Comparison of lidar and acoustic data

The residuals (residual = SHOALS depth - linear model) are shown on Figure 9. Because of the near linear relationship between SHOALS depth and acoustic depth, the residuals are approximately equal to (-) "Depth difference" as computed in figure 7 (i.e. residual ≅ {(SHOALS full density TIN) - (acoustic depth)}).

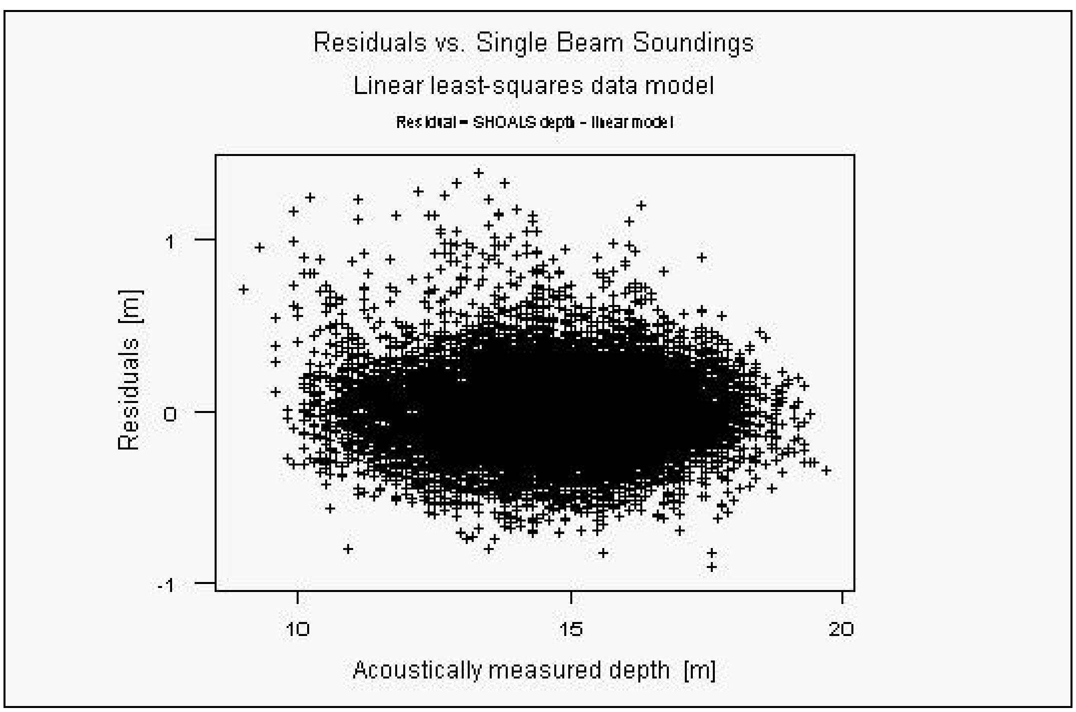

Figure 9 - Distribution of residuals

Figure 10 is a graph of the residuals against the normal probability distribution; note how the residuals greater than approximately 0.5 meters depart from the straight line y = x. Figure 10 highlights the fact that a small population of depth differences show a departure from the bulk of the comparison population. Referring back to Figures 7 and 9 we can see that, relative to the survey area's mean depth, the larger positive residuals are primarily located on the shoaler half of the survey. Some of these residuals may be attributed to the tendency to shoal-bias the echo-sounder data during field editing. Additionally, a higher percentage of soundings were collected in shoal areas--the reader is reminded that the MT MITCHELL data set has not been through final verification processing yet and erroneous depths may exist. It is also possible that a portion of the large positive residual population may be due to small contacts detected during the MT MITCHELL survey but missed during the SHOALS survey.

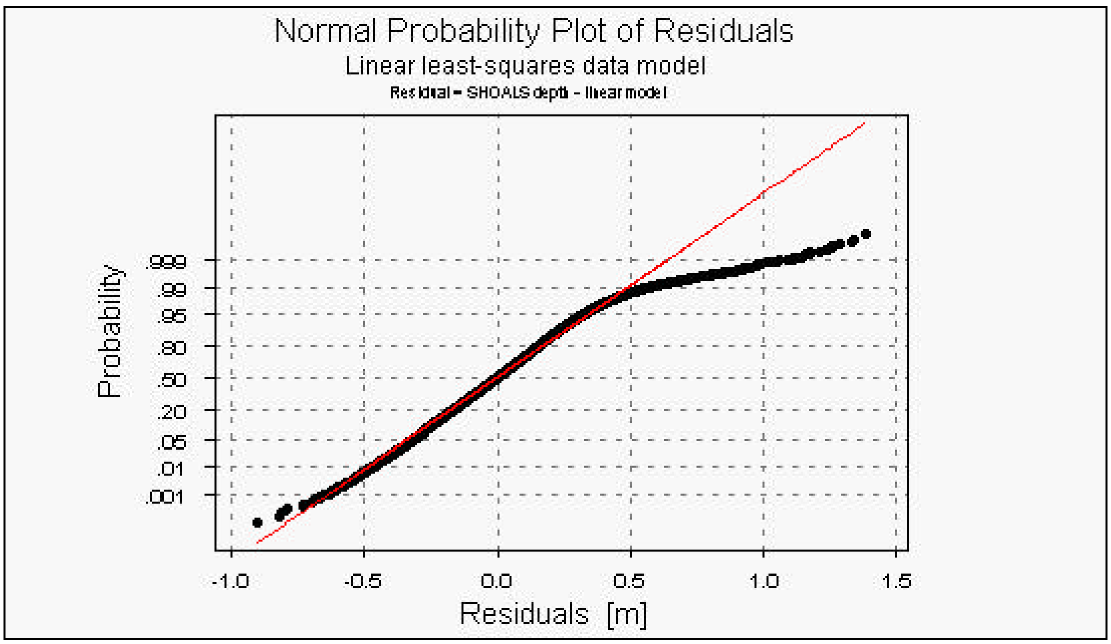

Figure 10 - Normal probability distribution vs. residuals

Obstruction Detection

As mentioned above in the **Survey Techniques** section, side scan sonar contacts estimated to be 1 meter or greater in height were investigated further by echo-sounder development and/or diver least depth measurement during the MT MITCHELL survey. A total of 18 obstructions were investigated by MT MITCHELL divers. 15 of these 18 obstructions are located in areas covered during the SHOALS project. 14 of the 15 objects are 1.5 meters or less in height; the remaining item is a 2.0-meter high coral-covered rock.

At the time of writing this paper, the 2.0-meter high rock and two other rocks measuring approximately 1.0 and 1.5 meters high were examined in the SHOALS data set. All three rocks were found manually in the SHOALS waveform signals. Currently the NOS-designed SHOALS waveform analysis algorithm is finely tuned around automatically finding bottom-like returns in water depths as shallow as one meter. Because of this bottom return-waveform shape dependence, only large targets will be detected. Each one of the three rocks examined were too small in their areal extent to trigger automatic detection.

Conclusion and Remarks

Several important insights regarding the detection of small submerged objects with lidar surveying methods are being learned from the NOS Tampa surveys. As this paper is being written, the Office of Coast Survey is finishing up a theoretical target detectability study for the SHOALS system. Alone, the SHOALS system should not be expected to conduct critical hydrographic surveys that require side scan sonar for small object detection. However, SHOALS-only projects will be able to operate in areas with less sensitive small object detection requirements. Results from on-going target detection studies and data from Tampa, FL SHOALS project and others will form an integral part in determining the best mix of techniques with which to accomplish NOAA's charting mission.

The comparisons between the Tampa SHOALS data and the NOAA-approved echo-sounder data show that SHOALS meets IHO depth-accuracy standards. Apart from general bathymetry, it is difficult to compare acoustic and lidar hydrographic survey methods and costs on equal terms. The fact that the success of lidar bathymetry is very much dependent on water clarity must also be kept in mind. NOS has planned a second SHOALS characterization survey, covering a portion of the NOAA Ship RUDE's OPR-B302 project in the Rhode Island Sound Corridor. However, since late July, 1995 water clarity has been insufficient to support lidar bathymetric operations.